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A cross-college team of educators has developed a collaborative, multi-disciplinary senior design course at Ohio University. This course offers an attractive opportunity for students from a variety of disciplines to work together in a learning community to accomplish a challenging task. It provides a novel multi-disciplinary learning environment where they will be encouraged to think about issues related not only to their own major, but more global issues that are extremely relevant to real-world design situations. The project has the potential to enhance and extend the reputation of the University as a leader in equipping Mechanical and Electrical Engineers, Computer Scientists, an Business students for the fast-paced, dynamic, team-oriented careers that are becoming the norm in industry. The proposed project for this activity is designing, constructing, programming, and controlling a team of robots for the international RoboCup competition. This event, featuring mobile robots competing in the game of soccer, promises to provide the University high-visibility, positive exposure to help recruit quality undergraduate students. The College of Engineering and Technology is currently seeking industrial sponsorship for the proposed RoboCup team. Project results will be used in a proposal to the NSF Education Directorate. Includes one figure: early conceptual design for RoboCup mobile robot. (Author)

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ROBOCUP: MULTI-DISCIPLINARY SENIOR DESIGN PROJECT

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ABSTRACT

A cross-college team of educators has developed a collaborative, multi-disciplinary senior design course at the University. This course offers an attractive opportunity for students from a variety of disciplines to work together in a learning community to accomplish a challenging task. It provides a novel multi-disciplinary learning environment where they will be encouraged to think about issues related not only to their own major, but more global issues that are extremely relevant to real-world design situations. The project has the potential to enhance and extend the reputation of the University as a leader in equipping Mechanical and Electrical Engineers, Computer Scientists, and Business students for the fast-paced, dynamic, team-oriented careers that are becoming the norm in industry. The proposed project for this activity is designing, constructing, programming, and controlling a team of robots for the international RoboCup competition. This event, featuring mobile robots competing in the game of soccer, promises to provide the University high-visibility, positive exposure to help recruit quality undergraduate students. The College of Engineering & Technology is currently seeking industrial sponsorship for the proposed RoboCup team. Project results will be used in a proposal to the NSF Education Directorate.

OBJECTIVE

When students graduate from the University they are equipped with skills relevant to a particular discipline. However, their education rarely prepares them for the situation that many encounter in the workplace: participation in multi-disciplinary teams. To enhance the undergraduate educational experience, the faculty involved propose to develop a multi-disciplinary senior design course within the College of Engineering & Technology and the College of Business.

The proposed multi-disciplinary senior design course involves curricular innovation, building a new multi-disciplinary learning community. Although an initial goal of the course is to enhance and extend senior design courses, the project focus will enable faculty to also transfer the collective research results into undergraduate education and to involve undergraduate students in research activities. The faculty involved intend to leverage the existing funding and demonstrated institutional commitment by submitting an NSF Education Proposal. Finally, the proposed project, RoboCup (mobile robots competing in the game of soccer), will bring positive recognition to the University via the team of students competing in this highly publicized, international competition. This will enhance the ability to recruit quality students to the University.

BACKGROUND

Professors from the School of Electrical Engineering and Computer Science, the Department of Mechanical Engineering and the Department of Management Information Systems have held meetings to consider the problem of educating students for success in multi-disciplinary team environments. The results of the discussions are (1) an analysis of the problem, (2) the means by which the faculty involved should test whether a proposed solution solves the problem and (3) a

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proposed solution. The remainder of this paper presents the results of the discussions and the plan to implement the solution.

The problem of educating students for success in multi-disciplinary team environments is one that needs to be addressed. Professional engineers are often confronted with the challenges of constructing, modifying and maintaining very large and complex systems, such as aircraft, spacecraft, ships and automated factories. Without exposure to the broad range of skills required by such challenges, engineers will not know how to approach them in the most effective way. For example, an electrical engineer tasked with developing an autonomous mobile robot for an automated factory may attempt to design and construct the entire robot herself. Such an approach is not likely to be as successful as one in which a mechanical engineer is involved with the motor, drive train and platform aspects and a software engineer contributes the algorithmic designs.

The current curriculum within the College of Engineering & Technology does not prepare students as well as it could for multi-disciplinary environments. Rather, depth and breadth are provided within a single discipline. For example, a software engineer learns:

- How to program a computer in several programming languages;
- Concepts for developing a broad range of specific software systems such as databases, operating systems, network protocols, compilers and intelligent reasoning systems;
- Methods for analyzing the complexity of software; and
- Techniques for software requirements analysis, design and testing.

A similar approach is taken within the other engineering disciplines. Such an approach does not provide exposure to the challenges inherent in a complex system requiring knowledge of multiple disciplines. Therefore, it does not allow the students an opportunity to learn the skills needed for success in such a project. Furthermore, it can give students the false notion that they can ignore certain aspects of a complex system. For example, a software engineer who is unaware of a software performance constraint that is derived from the physics of a system may develop software that simply ignores such a constraint, leading to eventual malfunctioning of the system. The faculty involved propose to address this serious problem.

How can one evaluate whether the proposed solution solves the problem? First, it must be determined whether the solution does indeed address the problem. A good solution will address the problem if and only if it offers the students an opportunity to develop the skills necessary for functioning in multi-disciplinary teams for the purpose of engineering complex systems. Second, one should consider whether the proposed solution could be implemented without causing other problems. It should not increase the length of time required to complete an engineering degree, and the depth and breadth provided by current engineering programs should not be compromised. The required course sequences should change very little. Finally, the issues of coordinating and assessing multi-disciplinary teams of students should be addressed.

POTENTIAL SOLUTIONS

When considering possible solutions to the problem, two candidates were identified. One possibility is to teach students about the skills developed in each discipline. While it is probable that this solution could be implemented without causing other problems, it would not provide the students with an opportunity to work with individuals in other disciplines; consequently, the depth of learning would not be very great. A second possibility is to have teams of students from various disciplines cooperate in an engineering endeavor. This would address the problem, since it would allow students from diverse disciplines to learn how to cooperate synergistically. Would it create additional problems?

Currently, Mechanical Engineering and Electrical Engineering curricula include a "Capstone Senior Design" course in which the students apply their skills to a complex problem in their discipline. Similarly, Computer Science students take a "Software Engineering" course in their final year. The faculty involved propose to have students in these courses work on multi-disciplinary team projects; this approach would avert all of the aforementioned problems, except for the coordination and assessment of multi-disciplinary teams. To address the issue of coordination within a multi-disciplinary team, the faculty involved propose to include students from the College of Business in each team. This will allow the business students to practice skills such as schedule planning and milestone tracking,

communication, integration and testing, risk mitigation. It would also allow the engineering students to focus on the engineering challenges and to benefit from the management skills of others. It is also proposed to utilize one TA from each engineering discipline. The responsibilities of each TA will include assistance with laboratory work, assessment of work and assistance with the multi-disciplinary curriculum development.

PRODUCTS

Since a multi-disciplinary team project addresses the problem and can be implemented in a manner that does not create additional problems, the faculty involved propose to conduct a pilot project during the 2000-2001 academic year. The specific products that the faculty involved will develop include:

- Course materials for a multi-disciplinary senior design course;
- A set of potential projects for such a course for future years;
- A reusable, extensible platform for multi-disciplinary senior design projects;
- Procedures and policies for multi-disciplinary team communication and coordination;
- A proposal to the National Science Foundation Education Directorate; and
- A scholarly publication for submission to an educational conference and/or journal.

ROBOCUP PROJECT

One question that needs an answer is "What would make a good Multi-disciplinary Project?" The problem of building a team of cooperating mobile robots is a good one. It involves mechanical, electrical and software design. It is sufficiently complex to present a challenge to students, but is feasible for them to complete in the three-quarter time allocated for a Senior Design course. Although an initial investment in hardware is requested from internal funds (more than equally matched by departmental funds), the result would be a *reusable* platform; thus, the cost in subsequent years would decrease because the senior design projects could involve incremental refinement of the robotic platform. Another reason for choosing this particular project is that there is an international competition that students can enter with their team of robots. The competition is RoboCup—a tournament in which teams of mobile robots compete in the game of soccer. The common goal of competing in the RoboCup event would help to promote cohesiveness and commitment within the multi-disciplinary team. Thus, the faculty involved request funds for representatives of the team to travel to the competition. Competing in the RoboCup event would be a valuable educational experience for the students. Another benefit of having the students compete is that it would increase the visibility of the University. RoboCup has been featured on the Discover Channel's Scientific America Frontiers program.

MULTI-DISCIPLINARY WORK EFFORTS

The cooperating mobile robots project offers many challenging aspects for Mechanical Engineers, Electrical Engineers, Software Engineers and Managers. The ME students will be responsible for design and integration of mechanical hardware and low-level control. The specific tasks are:

- Defining the specification of dynamic performance;
- Selecting/sizing the drive-train of the robot esigning/ fabricating/assembling the mechanical parts of the robot;
- Designing/fabricating/assembling a kicking mechanism;
- Designing/implementation/testing low–level servo control (software/hardware) with EE students;
- Development of on-line dynamic path planning;
- Documenting/communicating with EE, CS, MIS to integrate the overall system; and
- Testing/evaluating of the overall system with EE, CS, MIS.

The Electrical Engineers will contribute to the team in the following areas.

- Design and implementation of the robot's on-board computing hardware
- Design and implementation of the robot's on-board system software

- Design and implementation of the wireless communication system
- Selection and integration of the robot's on-board sensors
- Design and implementation of the motor drive and control system with ME students
- Overall system integration with ME, CS, and MIS students
- Evaluation and test of the overall system with CS, MIS students, and ME

The Software Engineers will focus on the following aspects of the problem.

- Design, development and testing of all software
- Vision and sensing processing
- Artificial Intelligence (Planning, Strategy analysis, and Learning)
- Distributed Systems
- Real-Time Computing

The MIS/Business students will apply the following skills.

- Resource Management
- Time Management
- Risk Assessment & Risk Control
- Unit & System Testing Design
- Teamwork & Leadership
- Quality Assurance
- Software Inspection & Walkthroughs
- System Planning, Analysis & Design

IMPACT AND EVALUATION

The initial project impact will be small in terms of number of students benefiting because the faculty involved plan a small pilot intentionally. However, assuming project success, this innovative multi-disciplinary approach to senior design courses could impact every senior in the respective disciplines (approximately 180 students graduated per year) in the future. The project focuses on three-quarter efforts, rather than just one quarter. Also, this project can serve as a model for the College of Engineering & Technology and potentially many areas within the University that can benefit from a multi-disciplinary senior capstone course approach. The project impact will be significant in improving the planned NSF Education proposal with concrete experience and demonstrated the University investment. The project will also bring name recognition to the University through the RoboCup competition.

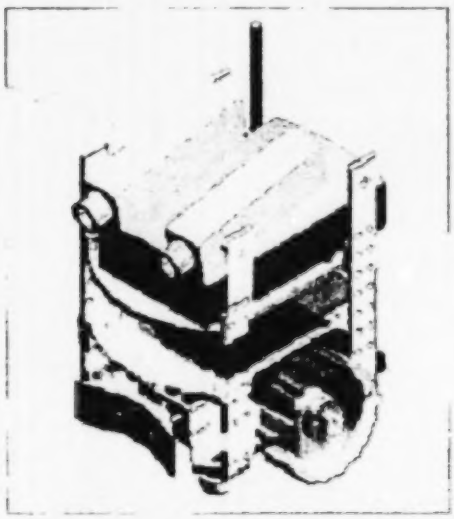
The one-year pilot project will be evaluated by comparing the multi-disciplinary student teams' results against those of senior students who go through the traditional single-discipline three-quarter senior design sequence. This will be challenging in that the hardware projects will be different; however, the quality, robustness, and depth of products can be compared between the single- and multi-disciplinary approaches. The faculty involved believe that the multi-disciplinary approach is significantly stronger; however, another important evaluation criterion is logistics: did the pilot project succeed in terms of large teams, different departmental administration, and different backgrounds? Part of the result will be a plan for improved multi-disciplinary teamwork in undergraduate education.

SUMMARY OF WORK TO DATE

The proposed RoboCup team has been holding collaborative, multi-disciplinary design meetings during Winter and Spring quarters, 2000. The faculty involved are primarily talking about the proposed multi-disciplinary senior design curriculum, but the faculty involved are also currently involving undergraduate students in preliminary mobile robot designs, sponsored by the NSF Research Experiences for Undergraduates

(REU) program. The figure below shows a CAD model of an early conceptual design for a mobile soccer-playing robot.

FIGURE 1
EARLY CONCEPTUAL DESIGN
FOR ROBOCUP MOBILE ROBOT



During Winter 2000 Dr. Peter Stone addressed the team regarding RoboCup via the Stocker Visiting Lecturer program. Dr. Stone, employed by AT&T, recently graduated from Carnegie-Mellon University (CMU), where he has competed successfully in RoboCup since its inception in 1997.

Two teams of Electrical Engineering undergraduates competed in an IEEE competition for mobile robots collecting steel and brass balls autonomously. Though this project had little input from Computer Science and Mechanical Engineering, the problem is related to mobile robots playing soccer, so the University has started building experience in this area.

Currently Mechanical Engineering is teaching ME 455, Mechatronics. The class project is to convert a mobile toy car from joystick control to autonomous on-board-computer-based control. This project is closely related to the RoboCup needs, spanning the software, electronics, and mechanical disciplines. This can be done better with involvement from the three areas rather than just one.

During the Fall and Winter 2000 and 2001 the students have enrolled in the various senior projects courses and have built prototype robot components. During the Spring 2001 the students implemented the prototypes and during the summer 2001 the competition was held. Results will be presented at various conferences in the Fall 2001. Multiple papers on various theoretical and teaching aspects of this project have been accepted and presented at several conferences in various disciplines.

VARIOUS BUDGET DATA

The graduate teaching assistants (TA) are crucial for project success, working with the PIs, undergraduate students, and technicians both on multi-disciplinary curriculum development and on practical robot hardware design, construction, programming, and control. The total requested budget is $24,000, for two teaching assistants working for four quarters at $3,000 per quarter. The Internal Education Fund is requested to provide half this amount and the departments will provide matching for an equal amount. The College of Engineering & Technology will also provide tuition scholarships for these eight quarters of work.

The hardware budget is intended to purchase required components for building the team of RoboCup robots. These components include motors, motor drive circuitry, PC boards, wireless communication equipment, sensors, and video cameras with frame grabbers, wheels, and gear transmissions. The early designs indicate a cost of approximately $3,500 per robot for six robots, plus a one-time cost of $1,000 for communication hardware, which is used for all six robots, for a total of $22,000 in hardware components. The Internal Education Fund is requested to provide $12,000 for hardware, to be partially matched with $1,000 from the College of Engineering & Technology, $1,000 from the Pace Grants Consortium, $6,000 from the Electrical Engineering and Computer Science department, and $2,000 from the Mechanical Engineering department.

A total of $500 is requested from the Internal Education Fund to provide required supplies for supporting robot construction. Though not shown formally as matching,

the College of Engineering & Technology and departments will contribute to supplies via existing stock and purchases.

The travel budget is intended to partially support: 1) sending a portion of the RoboCup team (PIs, undergraduate students, and TAs) to Seattle during the summer of 2001 to represent the University for the first time at the international, high-profile RoboCup competition; and 2) presenting project results (multi-disciplinary senior design projects) at an educational conference. The Internal Education Fund is requested to provide $5,000 for travel, to be matched equally by the College of Engineering & Technology ($3,000), and the departments ($2,000).

Finally, technician labor is required to assist students, TAs, and the PIs in producing polished, professional robots worthy of representing the University, built for reliability. The College of Engineering & Technology will provide the sole support, $1,000 for each of two technicians (machinist and hardware/software technicians). This will provide a total of 100 technician hours at $20 per hour.

CONCLUSION

This course/project offers the opportunity for a variety of disciplines to work together in a learning community to accomplish a challenging task. It provides a multi-disciplinary learning environment that does not exist on very many campuses. It encourages students to think about issues related not only to their own major, but more global issues that are extremely relevant to real world design situations. The project has the potential to enhance and extend the reputation of the University as a leader in equipping Mechanical and Electrical Engineers, Computer Scientists, and Business students for the fast-paced, dynamic, team-oriented careers that are becoming the norm in industry. The proposed project for this activity, the international RoboCup competition, promises to provide the University high-visibility, positive exposure to help recruit quality undergraduate students. This model could be adopted by any university with engineering, computer science and information systems departments.

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